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The Growth of Bigleaf Maple and Planted Conifers 14 Years after Maple Clump Thinning

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G. Harper, K. Thomas, and P. Comeau

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ABSTRACT

Bigleaf maple (*Acer macrophyllum* Pursh) is a native broadleaf commonly found in the coastal forests of the Pacific Northwest. Following harvesting, vigorous sprouting from cut stumps can create large, rapidly growing clumps of maple sprouts, which can severely reduce the survival and growth of neighbouring conifers. During 1996, ten 0.09-ha plots containing up to 490 bigleaf maple clumps per hectare (cph) were established. A series of maple clump thinning treatments ranging from 0 to 400 cph was assigned to the plots to study the effects of varying maple clump density on understorey light and conifer growth. Select maple clumps were removed by manually cutting all clump sprouts. Post-treatment results over 14 years indicated that the maple clump thinning treatments did not result in any long-lasting differences in conifer survival and growth. In contrast, the clump thinning treatments resulted in a significant decline in cut maple and an increase in uncut maple clump sprout density and volume increment with increased uncut maple cph. Conifer volume increment and total stand volume increment showed no response across the maple cph treatments. Stand periodic annual volume increment of the maple–conifer mixedwood plots ranged from 7.6 to 13.1 m^3/ha/yr over 14 years post-thinning.

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The range of bigleaf maple (*Acer macrophyllum* Pursh) extends from 51° latitude near Port Hardy, Vancouver Island to 38° latitude north of San Francisco, California (Minore and Zasada 1990). Along the British Columbia coast, bigleaf maple is a component of mature Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) stands in the Coastal Western Hemlock biogeoclimatic zone (Meidinger and Pojar 1991), and best growth occurs on the moist and rich soils of river terraces, floodplains, and seepage sites at relatively low elevations (below 300 m) (Haeussler et al. 1990; Minore and Zasada 1990). Bigleaf maple is moderately shade-tolerant and can survive in the understorey of mature conifer forests. Regeneration occurs from either seed or stump sprouts, with maple stumps sprouting vigorously after harvesting. Individual maple stumps can produce up to 60 basal sprouts, and shoots can grow 2 m or more in height annually (Figure 1) (Lauterbach and Warren 1982; Cole and Newton 1990). Bigleaf maple sprout clumps can reach a crown diameter of 5 m in 2 years, and by 40 years, a maple clump can cover an area as large as 100 m^2 (Thomas and Comeau 1998).

As a result, bigleaf maple sprout clumps are considered to be serious competitors of Douglas-fir (Haeussler et al. 1990). Sprout clumps can rapidly occupy available growing space and overtop planted conifers, resulting in increased mortality and reduced growth of the conifers (Knowe et al. 1995). In addition, maple sprouts can cause conifer damage when they come in contact

FIGURE 1 *An unmanaged bigleaf maple clump of stump sprouts after leaf fall.*

with branches and leaders, and heavy leaf litter from established maple stands can smother small seedlings.

Knowe et al. (1995) presented polynomial models that described the effects of bigleaf maple on Douglas-fir growth as a function of maple proximity and maple crown diameter. Their results suggest that young Douglas-fir (7–11 years old) may suffer from diameter and height growth reduction depending on the distance and crown size of the neighbouring bigleaf maple clump. Retaining bigleaf maple in mixture with Douglas-fir or other conifers may be valuable for stand nutrient cycling. Fried et al. (1990) found that total soil nitrogen, soil organic carbon, and rate of macronutrient cycling were much greater beneath bigleaf maple than beneath neighbouring Douglas-fir. In addition to possible enhancements to nutrient availability, the presence of maple may contribute to stand structure, species diversity, and landscape aesthetics. Bigleaf maple is also a valuable commercial tree species (Minore and Zasada 1990) capable of reaching 30 m in height and 120 cm in diameter. The wood is used for higher-value appearance-grade products, such as flooring, furniture, and millwork. Bigleaf maple is also being tapped for syrup production in some areas of the British Columbia coast.

Managing bigleaf maple clump and stump sprout density may offer the promise of increased maple sawlog yield and shortened rotations. Thinning young sprout clumps or reducing sprout density is likely to accelerate the growth of residual clumps or stems. To date, very few studies have been conducted to provide information on maple and maple–conifer mixedwood growth and yield (Knowe et al. 1995). During 1995, Thomas and Comeau (1998) established a bigleaf maple–conifer mixedwood study to provide stand- and tree-level information on the effects of varying maple clump and sprout density on the growth of neighbouring Douglas-fir and grand fir (*Abies grandis* [Dougl.] Lindl.) and on the growth of the maple. This paper presents results of 14 years of post-treatment measurements from the Thomas and Comeau (1998) study, documenting understorey light levels, stand-level productivity, and individual tree, clump, and sprout growth. An assessment of the impact of maple thinning treatments is provided in an attempt to focus on the operational implications to forest productivity, temporal stand dynamics, and mixed species management.

2 METHODS

The study site was located in a cutblock in the Coastal Western Hemlock xeric maritime variant (CWHxm2) approximately 13 km northeast of Port Alberni, British Columbia (49°20'39"N, 124°53'39"W). The cutblock was clearcut harvested in 1988 and planted with Douglas-fir and grand fir in 1989. In 1995, 240–400 evenly spaced clumps per hectare (cph) of bigleaf maple were found during the initial pre-treatment site assessment (Thomas and Comeau 1998). This paper presents results from ten 30 × 30 m plots where various clump thinning densities ranging from 0 to 400 cph were randomly assigned (Figures 2 and 3; Table 1.) Chainsaws and pruning saws were used to fell all sprouts arising from stumps within selected maple clumps that were left after the maple were harvested in 1988. All maple clump thinning treatments were completed during spring 1996. The thinning treatments attempted to create

FIGURE 2 *A tagged uncut maple clump 22 years post-harvest.*

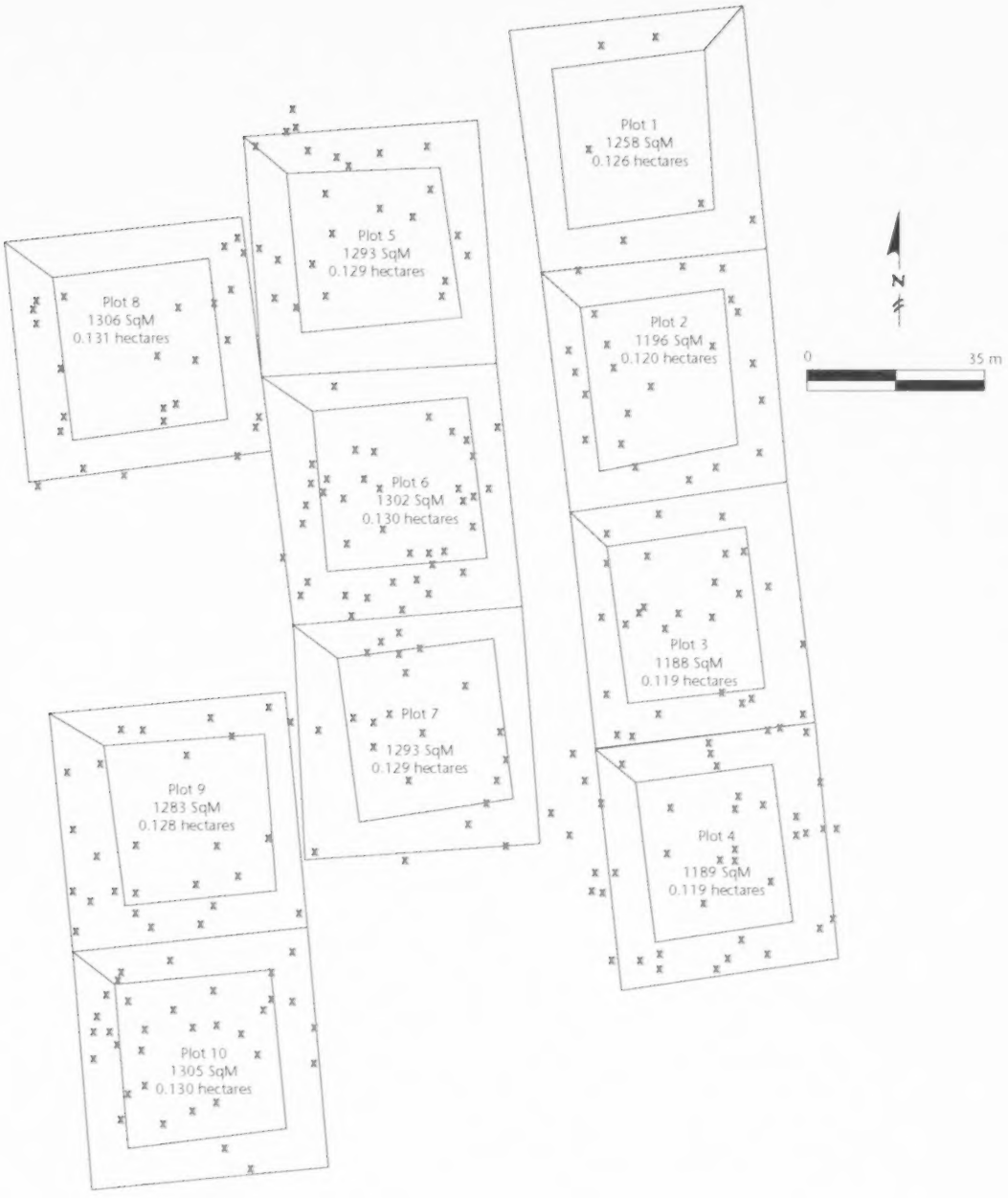

FIGURE 3 *Study plot layout (SqM = m², crosses denote maple clump locations).*

TABLE 1 *Summary of pre-treatment maple and conifer growth statistics for the 10 clump thinning treatment plots*

Clump thinning treatment uncut clump density (cph[a])	Pre-treatment uncut clump density (cph[a])	Average pre-treatment no. sprouts/ clump	% of clumps cut[b]	Average maple clump dominant sprout height (m)	Average maple sprout dbh (cm)	Conifer density (sph[c])	Average conifer height (m)	Average conifer root collar diameter (cm)
0	256	–	100	–	–	975	1.1	1.7
33	356	17.3	91	9.0	3.8	1425	1.7	2.2
67	244	15.9	68	10.3	5.6	1200	1.0	1.3
100	411	19.2	76	10.0	4.2	1050	2.2	3.5
133	300	19.4	56	8.9	4.1	1300	1.4	2.0
167	300	18.7	48	8.4	4.7	1275	2.1	3.2
200	289	17.8	31	10.3	5.7	1725	1.1	1.7
244	344	15.1	29	9.1	4.7	1575	1.5	1.7
300	378	14.4	18	9.2	4.3	825	1.8	2.5
400	489	15.0	18	9.2	4.3	1100	1.4	1.9
P value[d]	**0.0348**	0.0915	**<0.0001**	0.6428	0.9847	0.9174	0.7465	0.9939

a cph: clumps per hectare
b Spring 1996
c sph: stems per hectare
d *P* value value from PROC REG linear regression (ANOVA). **Bold** font indicates significant values.

a spatially uniform distribution of uncut maple clumps through the use of selective cutting. All plots were stem mapped pre-treatment (conifers and maple clumps) to facilitate the creation of spatially uniform uncut clump distribution. No other clump selection considerations were used. A 20 × 20 m measurement plot was established within each treatment plot, in which all maple clumps and conifers were tagged. Plot layout maps are provided in Thomas and Comeau (1998). Gendron et al. (1998, 2001) provide additional early stand development information on canopy light variability.

Prior to the thinning treatments, a 25-point grid of light assessment locations was established at 6-m intervals. Conifer measurements included diameter at breast height (dbh), root collar diameter (RCD), height, and crown radii (four cardinal directions). Maple clump measurements also included the number of sprouts per clump, sprout dbh, height of the dominant stem per clump, and clump crown radii. Stem volume for each maple sprout or conifer was calculated using Kozak (1988) taper equations. Heights for maple sprouts not measured were predicted from the height–dbh relationship of those measured (by plot and year) using the non-linear model fitting technique described by Omule and Macdonald (1991). Conifer and maple measurements were completed pre-treatment (spring 1996) and 1, 2, 3, 5, 9, and 14 years post-treatment (end of growing season for 1996–2009), which corresponds to 8–21 growing seasons post-harvest.

Light measurements were made using a LiCor LAI 2000 Plant Canopy Analyzer (LiCor Inc.) fitted with either a 90° or 180° view restrictor. Multiple readings were taken to cover the full 360° view, and each directional reading was timed to avoid the direct sun. Open-sky readings were also recorded using a second instrument located in a nearby opening. Prior to starting measurements, the LAI 2000 units were calibrated to each other in the open and their clocks were synchronized to the nearest second (Gower and Norman

1991). FV2000 software (LiCor Inc.) was used to determine diffuse non-interceptance (DIFN) values. LAI 2000 measurements were collected from 1996 to 2009.

Data analysis was completed using SAS version 9.1 (SAS Institute Inc. 2004). Statistical significance was based on $\alpha = 0.05$. Since treatment plots were not replicated, linear regression was used to test for significant change across the range of uncut maple clump treatment density on the dependent variables (plot averages for maple sprout number and size variables [dbh, height, and sprout volume], conifer size variables, stand-level density and volume increment, and DIFN). Pre-treatment maple clump density and pre-treatment maple clump sprout density were used as covariates to adjust for the possible influence of pre-treatment plot variation. Non-linear regression techniques were explored to improve linear fit statistics (Sit and Poulin-Costello 1994). Adjusted $R^2 = 1-[(n-1)/(n-p)]\ SS_E/SST_C$ (R^2_{adj}) where n = sample size, p = number of parameters, SS_E = residual sum of squares and SST_C = corrected total sum of squares was used for all non-linear equations to determine which was the most appropriate model (Cornell and Berger 1987). Residual plots were assessed visually for each fitted equation, and models were evaluated using root mean squared error (RMSE) and R^2_{adj}. Caution was used in interpreting linear regression statistics (presented P values are from linear regression unless otherwise noted). Statistical significance was considered to be evidence of a possible thinning treatment response; however, the inference was not considered to be conclusive (Neter et al. 1990).

3 RESULTS

Table 1 provides pre-treatment statistics for maple clumps, clump sprouts, and conifers found within the treatment plots. The only significant pre-treatment regression test was in pre-thinning clump densities. The average pre-treatment sprout number per clump, height, clump sprout dbh, and crown area ($P = 0.5845$) did not change significantly across treatments. The average pre-treatment number of sprouts per clump was approximately 17, average height was 9.4 m, and average dbh was 4.6 cm. In comparison, the average conifer (primarily planted Douglas-fir and grand fir) was 1.5 m tall with an RCD of 2.2 cm, thus indicating an understorey position within and beneath the developing maple clump canopy. Minor numbers of western redcedar (*Thuja plicata* Donn) and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) naturals were also recorded (≤ 75 stems per hectare [sph]). No significant response in conifer density, height, or RCD was noted across the treatment range pre-treatment (Table 1). Regression analysis by conifer species also suggested there was no pre-treatment change in RCD, height, density, or crown length and width ($P > 0.23$, data not shown) within the range of clump treatment density.

Post-treatment regression analyses with or without pre-treatment covariates were compiled. Pre-treatment maple clump density and maple clump sprout density were used as covariates to explore the pre-treatment influence of maple clump plot variation on post-treatment regression results. The use of pre-treatment covariates did not significantly change the post-treatment interpretations from those without pre-treatment covariates. However, two

cases did occur where conflicting statistical evidence was found between the two covariate- and non-covariate-based regressions. Average number of sprouts per uncut clump during year 2 (Table 2, covariate: pre-treatment maple clump sprout density), and average uncut sprout dbh during year 14 (Table 3, covariate: pre-treatment maple clump density) resulted in $P = 0.0227$ and $P = 0.0349$, respectively. Alternative covariate regression and non-covariate regression P values for the same two variables were all ≥ 0.6035. These two incidents of conflicting results were conservatively interpreted as insufficient evidence of a treatment response.

TABLE 2 *Maple clump sprouting activity 2 (1997) and 14 (2009) years post-treatment*

Clump thinning treatment uncut clump density (cph[a])	Average no. sprouts/cut clump (1997)	Average no. sprouts/cut clump (2009)	% of cut clumps dead or rated poor (2009)[b]	Average no. sprouts/uncut clump (1997)	Average no. sprouts/uncut clump (2009)
0	124.6	12.5	13.0	–	–
33	106.4	10.3	41.4	21.7	10.0
67	196.4	15.5	13.3	16.3	9.9
100	52.3	10.8	46.4	22.8	9.1
133	95.0	8.6	66.7	22.9	9.3
167	64.4	4.5	76.9	25.4	9.9
200	79.3	8.8	87.5	21.0	8.6
244	61.8	7.0	66.7	18.0	7.9
300	80.0	7.2	83.3	19.9	6.2
400	32.9	10.0	87.5	19.4	7.5
P value[c]	**0.0442**	0.1584	**0.0030**	0.6035	**0.0047**

a cph: clumps per hectare
b clumps found dead or suppressed and of poor vigour
c P value from PROC REG linear regression (ANOVA). **Bold** font indicates significant values.

TABLE 3 *Summary of maple and conifer growth statistics for the 10 clump thinning treatment plots 14 years post-treatment (2009)*

Clump thinning treatment uncut clump density (cph[a])	Average uncut maple clump dominant height (m)	Average cut maple clump dominant height (m)	Average uncut maple sprout dbh (cm)	Average cut maple sprout dbh (cm)	Average conifer height (m)	Average conifer dbh (cm)
0	–	13.9	–	7.7	9.7	10.4
33	14.9	11.8	9.6	6.5	9.9	10.4
67	17.9	14.4	13.1	8.3	8.2	9.8
100	15.2	11.6	9.6	6.4	11.3	12.4
133	16.4	8.4	10.4	3.7	9.4	9.2
167	17.2	8.9	11.7	3.8	11.3	11.0
200	20.0	7.6	14.1	3.7	5.5	6.4
244	17.3	8.7	10.9	4.2	7.5	7.2
300	16.3	5.5	10.2	2.0	10.4	11.2
400	17.5	10.5	9.9	3.6	5.5	5.6
P value[b]	0.3891	**0.0449**	0.7741	**0.0057**	0.1475	0.0843

a cph: clumps per hectare
b P value from PROC REG linear regression (ANOVA). **Bold** font indicates significant values.

As expected, the maple clump thinning treatments resulted in vigorous cut clump re-sprouting, with a range in average number of sprouts per clump of 33–196 two growing seasons post-thinning (Table 2). The number of sprouts per cut clump decreased with increasing cph of uncut maple (Table 2). In comparison, no significant trend in the average number of sprouts per uncut clump 2 years post-thinning was noted across treatments (overall $\times = 21$, Table 2). However, conflicting evidence from the pre-treatment covariate analyses of uncut sprout density 2 years post-thinning ($P = 0.7839$ and $P = 0.0227$ for covariates pre-treatment clump density or clump sprout density, respectively) was interpreted as insufficient evidence of a significant trend. Fourteen years post-treatment, the average number of sprouts per cut clump ranged from 5 to 16, and the percentage of cut clumps that were dead or rated as in poor health (suppressed) exceeded 65% for all uncut clump densities > 100 cph ($R^2_{adj} = 0.65$) (Table 2). Also after 14 years, cut clump sprout height and average sprout dbh declined with increasing uncut maple density (Table 3). In the 400 uncut maple cph treatment, only one cut clump remained alive (out of a total cut of eight) 14 years post-treatment. Cut clump sprout dbh ranged from 2 to 8 cm, and height ranged from 6 to 14 m 14 years post-treatment (Table 3).

Understorey light levels (DIFN) declined with increasing uncut maple clump density during 1996 and 1997 (Figure 4). As the uncut maple clump

FIGURE 4 *Study plots with stump sprout maple clumps and planted conifers.*

crowns expanded over the 14 years post-treatment, the average uncut maple clump crown area increased from 23 to 43 m², which resulted in declining average DIFN. Immediately after clump thinning (prior to leaf-out, May 1996), DIFN levels were <70% only in the 300 and 400 cph treatments. However, by July of the same year (post leaf-out), only the 0 cph treatment had an average DIFN >70%, and the >300 cph treatments had <30% DIFN. In August 2000 (5 years post-treatment), all treatments had average DIFN levels <25% (data not shown). During August 2009, all treatment plots had declined to <3% average DIFN, indicating complete canopy closure. Non-linear regression indicated that a series of quadratic models best described the DIFN change with clump density (Figure 5).

By the fall of 2009 (14 years post-treatment), the uncut maple clumps had grown for 22 years since cutblock harvesting (Figures 2 and 4). The resulting closed canopy was composed predominantly of maple with an average height of 15–20 m (Table 3). Maple clumps had an average crown area of 29–57 m² (data not shown) and an average sprout dbh of 10–14 cm (Table 3). The average number of uncut sprouts per clump declined with increasing uncut maple clump density (Table 2). However, no statistically significant changes were found in uncut maple clump height, sprout dbh, and clump crown area at any year post-treatment ($P > 0.15$, crown area data not shown). Conflicting evidence from the pre-treatment covariate analyses of average sprout dbh 14 years post-treatment was interpreted as insufficient evidence of a significant treatment response. Also, no significant response was noted in Douglas-fir and grand fir dbh, height, and crown area over the 14 years post-treatment

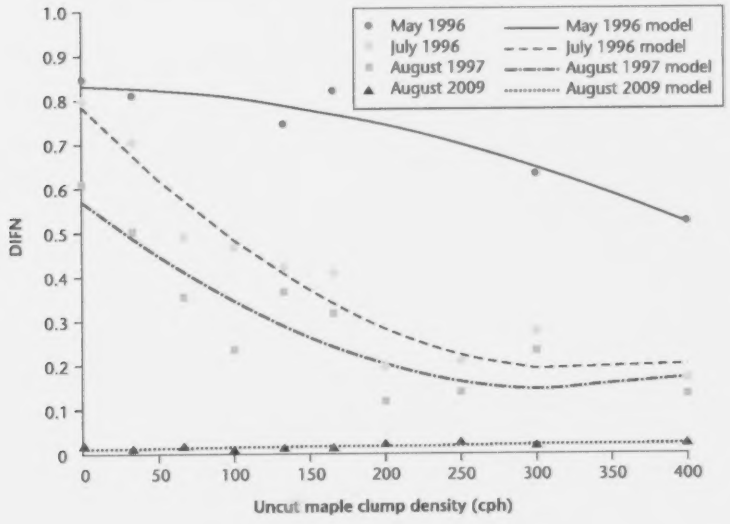

FIGURE 5 *Average light levels (DIFN at ~1.5 m) associated with maple clump thinning treatment densities. Lines represent fitted quadratic models ($Y = a + bX + cX^2$, where Y = DIFN and X = uncut maple clumps per hectare [cph]) for May 1996 ($P = 0.018$, $R^2_{adj} = 0.89$, RMSE = 0.043), July 1996 ($P < 0.0001$, $R^2_{adj} = 0.91$, RMSE = 0.064), August 1997 ($P = 0.0029$, $R^2_{adj} = 0.76$, RMSE = 0.081), and August 2009 ($P = 0.1360$, $R^2_{adj} = 0.27$, RMSE = 0.0044).*

(Table 3, $P > 0.0843$, some data not shown). By 2009, the average conifer height was 8.9 m and average dbh was 9.4 cm. The tallest dominant conifers averaged 18.3 m (≤75 sph), which was comparable to the height of the dominant uncut maples.

Figure 6 presents uncut maple clump sprout density on a sprouts per hectare basis in relation to top height (i.e., the height of the 100 largest dbh maple sprouts per hectare) for all treatments, and represents the series of multiple measurements from pre-treatment. In general, uncut maple clump sprout density declined with increasing top height or age; however, within the first five measurement periods, two distinct increases in sprout density were apparent in all treatments: the first year post-treatment and 4 years post-treatment. These increases in sprout density were net of the concurrent processes of sprout mortality and initiation (data not shown), with a change in amplitude dependent on uncut maple clump treatment density.

Stand-level density for the uncut clump sprouts, conifer stocking, and cut clump sprouts 14 years post-treatment is presented in Figure 7. Regression results suggested there was no significant trend in total stand density and conifer density across treatments ($P = 0.4002$, 0.7806, respectively). No clump mortality was noted in any of the uncut clumps except for one clump each

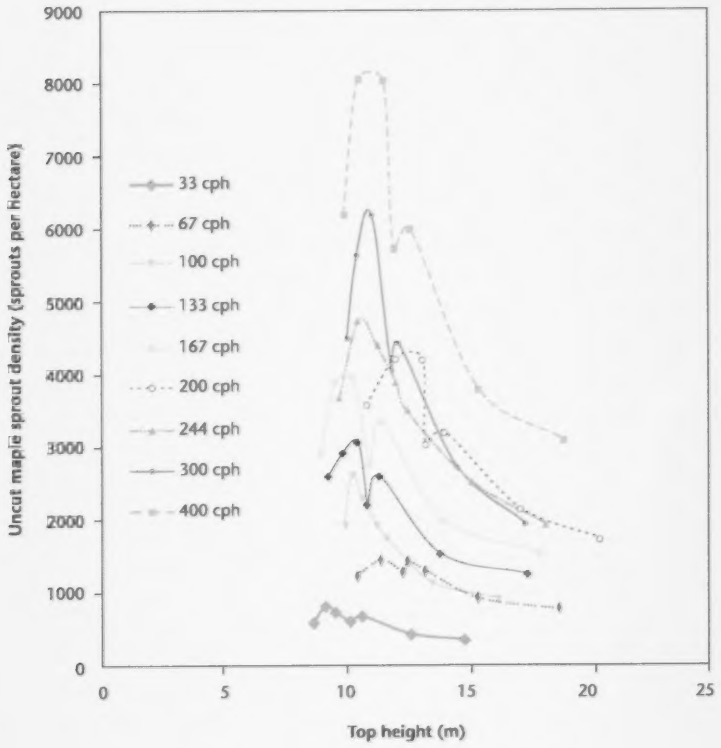

FIGURE 6 *Uncut maple clump sprout density in relation to maple clump top height (the height of the 100 largest dbh maple sprouts per hectare [multiple measurements from pre-treatment]). Points are joined by lines for illustration only (cph: clumps per hectare).*

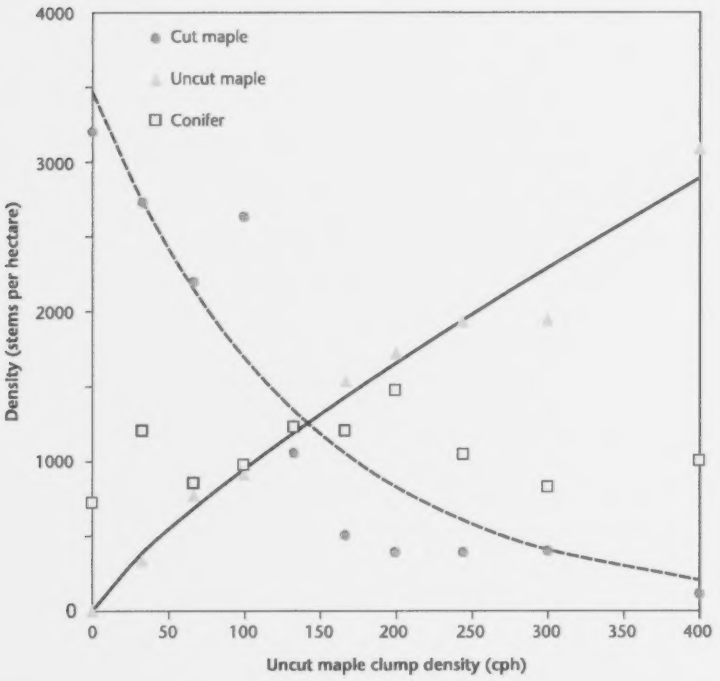

FIGURE 7 *Density of all planted conifers, uncut maple, and cut maple sprouts 14 years post-treatment in relation to uncut maple clump thinning treatment density (clumps per hectare [cph]). (Linear regression [ANOVA] P = 0.7806, < 0.0001, and 0.0009, respectively; total stand density P = 0.4002). Lines illustrate fitted non-linear regression Equation 1 (uncut maple, solid line) and Equation 2 (cut maple, dashed line).*

in the 300 and 400 cph plots. Uncut maple sprout density increased and cut maple sprout density decreased with increasing uncut maple cph treatments ($P = 0.0009$). The uncut sprout density increased exponentially with uncut clump density as described by a power function model:

$$UC_d = 23.328C^{0.805} \; n = 10 \; R^2_{adj} = 0.96 \; \text{RMSE} = 164.27 \; P < 0.0001 \qquad (1)$$

where UC_d = density uncut clump sprouts (sph) and C = uncut clump density (cph).

The cut clump sprout density declined with increasing uncut maple cph as approximated by a Type II exponential function:

$$CC_d = e^{8.151 - 0.0072C} \; n = 10 \; R^2_{adj} = 0.88 \; \text{RMSE} = 439.13 \; P < 0.0001 \qquad (2)$$

where CC_d = density cut clump sprouts (sph) and C = uncut clump density (cph).

Both the 0 and 400 uncut maple cph treatments resulted in a similar high total sprout density of approximately 3200 sph (Figure 7). Attempts to fit total stand density to cph density using nonlinear regression did not improve the

linear model result ($P = 0.4002$), which was suggestive of competition between the two maple clump cohorts (cut and uncut).

Figure 8 presents volume increment results over the 14-year post-treatment period for the various stand components: uncut maple clumps, cut maple clumps, and conifers. There was no significant linear trend in conifer volume increment with increased uncut cph ($P = 0.1433$), although an apparent decline was visible. Uncut and cut maple clump components significantly increased ($P = 0.0186$) and decreased ($P = 0.0228$) in volume increment, respectively, and non-linear functions similar to those fit to density improved model predictions:

$$UC_v = 4.037C^{0.609} \; n = 10 \; R^2_{adj} = 0.62 \; \text{RMSE} = 34.18 \; P = 0.0002 \qquad (3)$$

where UC_v = volume increment uncut clump sprouts (sph) and C = uncut clump density (cph).

$$CC_v = e^{4.358 - 0.0214C} \; n = 10 \; R^2_{adj} = 0.90 \; \text{RMSE} = 8.55 \; P < 0.0001 \qquad (4)$$

where CC_v = volume increment cut clump sprouts (sph) and C = uncut clump density (cph).

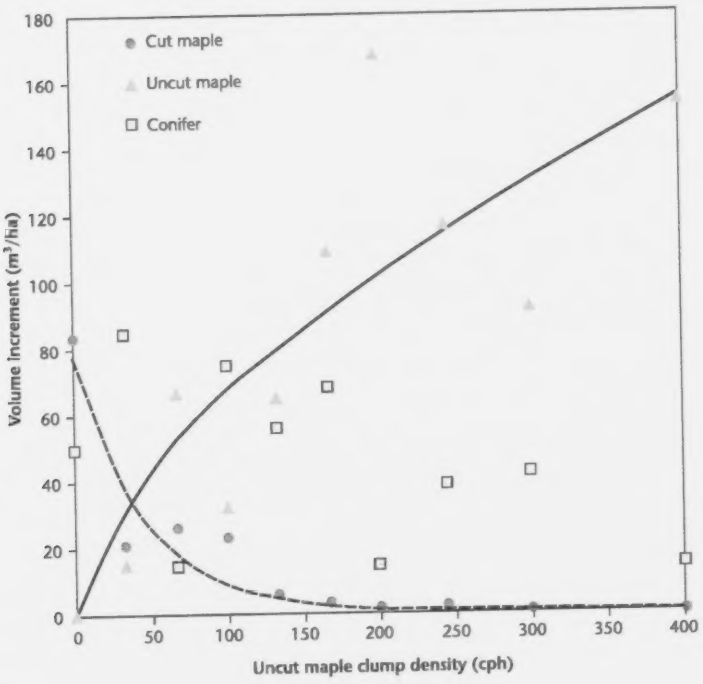

FIGURE 8 *Volume increment over the 14-year post-treatment period for the planted conifer, uncut maple clump, and cut maple clump stand components in relation to uncut maple clump thinning treatment density (clumps per hectare [cph]) (Linear regression [ANOVA] P = 0.1433, 0.0186, and 0.0228, respectively; total volume increment P = 0.0888). Lines illustrate fitted non-linear regression Equation 3 (uncut maple, solid line) and Equation 4 (cut maple, dashed line).*

Linear regression of total volume increment and total volume (data not shown) suggested there was no trend across the clump thinning treatments 14 years post-treatment ($P = 0.0888$ and $P = 0.1305$, respectively). Volume increment Equations 3 and 4 indicated there was an exponential increase in uncut maple clump volume and a concurrent decline in cut maple clump volume with increasing uncut cph.

Size–density trajectories for the average conifer and maple sprout volume with density calculated on a per hectare or per clump basis are presented in Figures 9 and 10, respectively. The conifer stand component trajectories (Figure 9) describe the various treatment plot size–density movement towards a similar asymptote as time elapses, irrespective of the initial variation in size and density. A similar presentation of uncut maple sprout size (Figure 10A) suggests that the size–density trajectory level or upper boundary varies across the treatment range, even though all plots appear to have a similar size–density trajectory slope. Figure 10B presents the uncut maple sprout size on a sprout per clump density basis rather than a sprout per hectare basis (Figure 10A). The result is a compression of the various treatment sprout size–density trajectories to more closely follow with a single upper boundary level at an sph basis.

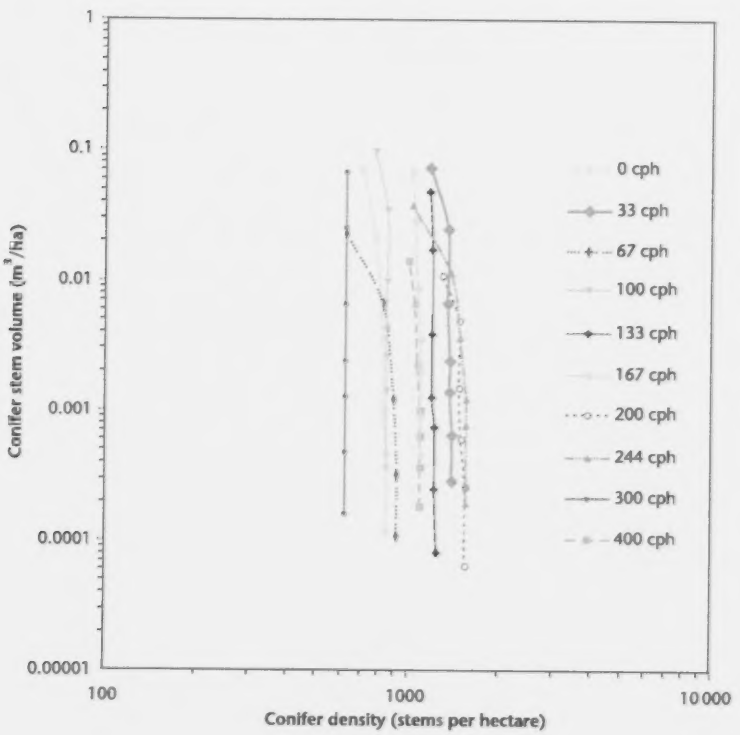

FIGURE 9 *Size–density trajectories for the average planted conifer stem volume in relation to density (stems per hectare) based on uncut maple clump thinning treatment (cph: clumps per hectare).*

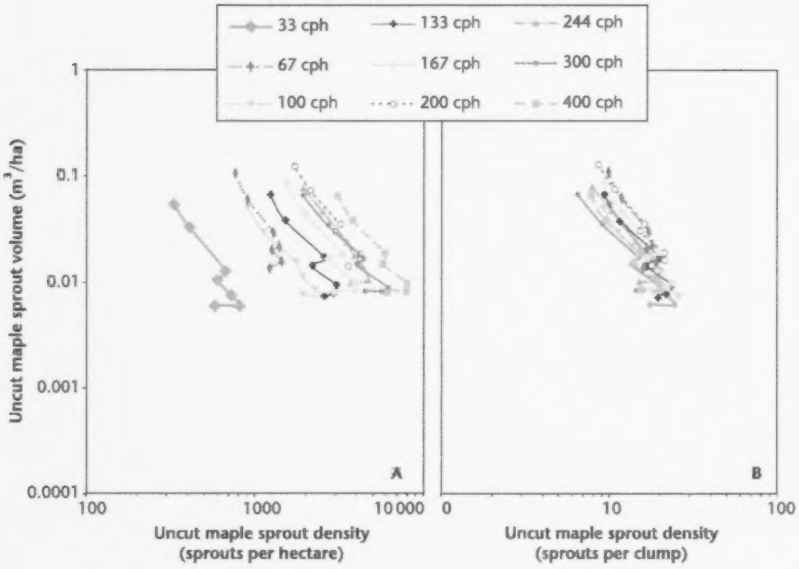

FIGURE 10 *Size–density trajectories for the average uncut maple sprout volume in relation to maple sprout density on a per hectare basis (A) and a per clump basis (B) according to uncut maple clump thinning treatment (cph: clumps per hectare).*

4 DISCUSSION

4.1 Uncut maple clumps

The average number of uncut maple sprouts per clump generally declined from 21 to 9 over the 14-year post-treatment period, with a significant reduction in sprouts per clump noted in the more dense maple cph treatments (Table 2). However, no response in average sprout height and dbh (Table 3) for the uncut maple clumps after 14 years post-treatment was evident. During the first 5 years post-treatment (Figure 6), the short-term increase in the number of sprouts per clump indicated that new sprouts were continuing to initiate and grow 10–12 years after harvesting. Most of these younger sprouts subsequently died due to their small size, shading, and competition from the larger clump sprouts. Average dbh and height for the uncut maple clump sprouts was 11.1 cm and 17.0 m, respectively, indicating an average growth of 6.5 cm and 7.6 m, respectively, over 14 years post-treatment. The significant increase in uncut maple clump stand volume increment with increasing treatment cph (Figure 8), combined with the lack of sprout size treatment response, indicates that, at the stand level, clump volume growth was dependent on clump density and not sprout dbh and height growth, which was unchanged across treatment cph.

4.2 Cut maple clumps

Maple clump sprout numbers can easily exceed 200 sprouts per clump in the first years after harvesting (Tappeiner et al. 1996), but clump sprout density rapidly declines due to self-thinning. Peterson et al. (1999) showed that mature maples originating from coppice declined to an average of four sprouts.

Similar clump self-thinning results were obtained in this study. By year 2 after thinning, the cut maple clumps had vigorously re-sprouted, with sprouts per clump declining across the treatments from an average re-sprouting of 125–33 sprouts per clump. This suggested that the presence of the uncut maple clumps was having an inpact on sprouting vigour, possibly through increased canopy shading and declining light levels. The average number of sprouts per cut clump for all treatments had declined to 10 after 14 years, with no significant linear change noted in the number of sprouts per clump across the treatments. However, cut clump mortality and growth suppression increased with uncut cph density. Cut clump component stand volume increment over the 14 years post-treatment was ≤ 5 m³/ha for >100 cph and 21–83 m³/ha for <100 cph (Figure 8).

4.3 Planted conifers

Stand- and tree-level statistics for the planted conifers (Douglas-fir and grand fir) suggested there was no significant treatment impact on density, height, diameter, and crown growth pre-treatment or 1 year or 14 years post-treatment. Conifer volume increment (14-year post-treatment period for Douglas-fir and grand fir combined) ranged from 14 to 85 m³/ha and was not affected by the maple cph treatments, contrary to the expectation that the lower cph treatments may have enhanced conifer growth (especially Douglas-fir, which is more shade-intolerant than grand fir). Results 14 years post-treatment indicated that the clump thinning treatments had little operational impact on understorey light (DIFN) levels, conifer size, and uncut maple clump growth. Vigorous re-sprouting and growth of the cut maple clumps failed to provide any real advantage to the planted conifers in the 0 or low-density uncut cph treatments. In retrospect, it would have been valuable to have included a treatment that completely removed the cut clumps by repeated manual cutting or herbicide application. Basal bark application of triclopyr (Release) herbicide provides effective control of bigleaf maple and can be applied either prior to or following planting (Wagner and Rogozynshi 1994). Providing for a treatment that was completely void of maple clumps would allow for an unfettered conifer growth comparison.

4.4 Stand level

Analysis of total stand volume increment and total density 14 years post-treatment indicated there was no change across the maple cph thinning treatments, even though differences in the cut and uncut maple clump stand components were found. Clump thinning treatments also had no impact on conifer density and conifer volume. In general, 14 years after treatment, the planted conifers had been overtopped by the taller maple canopy (both cut and uncut). Overall, the maple clump thinning treatments failed to reduce maple competition to the extent necessary to see operationally significant conifer growth responses (Knowe et al. 1995). The cut and uncut maple density and volume increment results (Figures 7 and 8, Equations 1–4) were analogous to those of a replacement series yield component plot of varied mixture (Kelty 1992). Plot-to-plot variation in site productivity appears to have influenced total stand volume growth as much as any of the maple clump thinning treatments.

Size–density trajectories were explored to characterize stand development for the average conifer and the cut and uncut maple components. Visual comparison of the maximum size–density relationships between maple from stump clumps with those of the planted conifers showed important differ-

ences. The self-thinning trajectories of the planted conifers followed expectations of a typical development pattern (Westoby 1984; Jack and Long 1996). However, the maple clump sprouts did not appear to follow expected norms when presented on a sprout or stem per hectare basis (Figure 10A). The wide range of plot trajectories for the uncut maple sprouts suggested an independence from density, even though similar slope and maximum stem size of the individual boundary relationships were apparent (similar uncut sprout sizes across a range of sprout densities). As already noted, after 14 years post-treatment, uncut sprout dbh and height were unchanged across the cph treatments, even though the number of sprouts per uncut clump significantly declined with increasing cph. The importance of defining density in the interpretation of maple clump trajectory becomes apparent. Maple sprout density defined on a sprouts per clump basis resulted in a more compressed and satisfying fit to the conventional self-thinning pattern observed with single-stem individuals (Figure 10B). It was therefore obvious that maple development in this trial was not dependent on stand clump density and that changes in sprout size–density relationship occurred within clumps and not between clumps. This finding is analogous to the discussion of competitive thinning in coppice or among ramets as described by Westoby (1984).

5 MANAGEMENT IMPLICATIONS

1. In this study, the bigleaf maple clumps clearly dominated the stand dynamics due to superior growth performance, canopy dominance, and competitive advantage over the planted Douglas-fir and grand fir. These observations are not new. The implications are that any attempts to control maple clump presence to improve conifer performance are best done with herbicides (Wagner and Rogozynski 1994) or stump removal treatments.
2. The total stand volume increment ranged from 106 to 183 m^3/ha (7.6–13.1 m^3/ha/yr) in a 14-year period. Such large stand volume increments in a relatively short period are comparable to high-site red alder (*Alnus rubra* Bong.) and managed Douglas-fir plantations (Mitchell et al. 2007). As a result, there may be considerable merit in managing dense maple clump origin stands for short-rotation fibre plantations and hardwood timber.
3. Size–density observations suggest that maple clumps develop independently, with sprout growth depending largely on within-clump density. This indicates that maple clump management should be a coppice-based management regime.

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